# Protected Areas and Biodiversity Conservation I: Reserve Planning and Design

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# Protected Areas and Biodiversity Conservation I: Reserve Planning and Design

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This module is the first in a two-part series entitled *Protected Areas and Biodiversity Conservation*. The objective of this module is to introduce the topic with a theoretical focus, covering the rich and extensive body of literature focusing on protected area (PA) objectives, design, and planning. Ultimately, however, the implementation and effectiveness of PAs are influenced by diverse social, economic, and political factors. Therefore, the second module in the series, *Protected Areas and Biodiversity Conservation II: Management and Effectiveness*, elaborates on management and human aspects of PAs, including policy, governance, financing, enforcement, efficacy, monitoring, and the future of protected areas. For complementary information pertaining to PAs in the marine *realm*, please see the NCEP module *Marine Protected Areas and MPA Networks*.

## Introduction

A protected area has been defined by the *World Conservation Union (IUCN)* as an "area of land and/or sea especially dedicated to the protection and maintenance of *biological diversity*, and of natural and associated cultural resources, and managed through legal or other effective means" (IUCN, 1994). While other definitions may have been adopted by individual states or organizations, the IUCN definition is widely accepted. Protected areas, also known as parks or reserves, have been established at international, regional, national, state, and municipal scales, and many are linked as *networks* or systems.

### Historical Origins of Protected Areas

Protected areas have deep historical roots: they have existed in varied forms in diverse ancient cultures, dating back to early pre-agrarian societies in Asia and the Near East (Allin, 1990; Runte, 1997). Chinese and South American civilizations from 3000 years before present have recorded decrees setting aside land to protect plants and animals (Sterling, 2002). Sacred forest groves that prohibited all forms of extractive use represent an early manifestation of protected areas (Chandrashekara and Sankar, 1998). Royalty created reserves, such as land set aside for game hunting, to exclude commoners. The unparalleled scale of ecological change stemming from the rise of colonialism and European expansion spurred conservation action and protected area establishment. Many of these colonial European measures and philosophies were built on early Indian and Chinese principles of conservation (Sterling, 2002). The establishment of the first national parks in the United States, such as Yosemite and Yellowstone, stemmed from a philosophy that valued these areas as grand monuments (Runte, 1997). The rise of this "national parks movement" in the United States is believed by some to have occurred in response to the industrial revolution that set humankind upon a course altering natural *landscapes* at a prodigious rate. The rapid and unprecedented transformation of the land provoked a call for the preservation of what was so rapidly lost (Runte 1997).

### Protected Areas Today: Type and Extent of Coverage

Protected areas form the cornerstone of biodiversity conservation efforts worldwide (Margules and Pressey, 2000). A global system of PAs currently protects close to 105,000 sites over approximately 20 million km2, covering about 12.2 percent of the planet's land area (Chape et al., 2005). In contrast in 1982 this network was reported to encompass only 3.5% of the planet's earth surface. Most of the current PAs are terrestrial, while marine areas protect some 2 million km2, only about 0.5 percent of the world's oceans (Chape et al., 2005). The United Nations List of Protected Areas contains updated information on these protected areas (http://www.unep-wcmc.org/wdpa/unlist/2003_UN_LIST.pdf).

More than 4,500 PAs have been established under various global treaties and conventions, including World Heritage Sites and Man and Biosphere Reserves (Table 1). PAs are also a focus of other international agreements, including the Convention on Biological Diversity (CBD), the Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar), and the Convention on the Conservation of Migratory Species of Wild Animals (CMS). The United Nations Convention on the Law of the Sea (UNCLOS) defines national rights to territorial seas, a necessary precursor to Marine Protected Area (MPA) establishment (see also NCEP module *International Treaties for Marine Conservation and Management*).

On a regional level, there are transboundary protected areas and networks. The transnational Turtle Islands Heritage Protected Area in the Philippines and Malaysia, for example, was implemented to protect regional populations of highly migratory sea turtles. Recognizing that conservation issues often transcend state borders, the Association of South East Asian (ASEAN) Declaration on Heritage Parks and Reserves (Bangkok, 1984) is designed to protect eleven sites in the nations of Brunei Darussalam, Indonesia, Malaysia, the Philippines, and Thailand (www.aseansec.org/1491.htm). In addition, there are PA-related regional agreements for European sites, such as the Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean governed

**Table 1. Types of Protected Areas Included in the Global System (UNEP, 2003)**
Each entry in the United Nations List of Protected Areas typically includes information for each country regarding PA name, geographic coordinates, size, IUCN category if applicable, and year of designation.

| PA Type | Examples (Chape et al., 2003) |
|---|---|
| **National Sites** – areas of national designation | National parks, nature reserves, wildlife sanctuaries |
| **International Sites** – areas designated by international instruments, or treaties | **World Heritage Sites.** The Convention Concerning the Protection of the World Cultural and Natural Heritage aims to protect areas of outstanding cultural, natural, or mixed value, fostering international cooperation in safeguarding these important areas. The Convention was established in Paris in 1972, and entered into force in 1975. |
| | **Man Biosphere Reserves.** The United Nations Educational, Scientific and Cultural Organization's Man and Biosphere (UNESCO-MAB) Reserves are globally recognized ecosystems where biodiversity conservation and sustainable use are joint goals. These terrestrial and marine sites are "designed to promote and demonstrate a balanced relationship between people and nature". Reserves are nominated by national governments and remain under their sovereign jurisdiction. |
| | **Wetlands of International Importance (Ramsar Sites).** The Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar, Iran, 1971) provides a framework for international cooperation in the conservation of wetland habitats in signatory states' territories. The Convention was signed in Ramsar, Iran, in 1971, and entered into force in 1975 (Box 2). |
| | **European Commission Directive on the Conservation of Wild Birds (Birds Directive, 1979).** Designates Special Protected Areas (SPAs) declared by European Union Member States in response to the Birds Directive to protect avian fauna and their habitats. The Birds Directive entered into force in 1981 and imposes legal obligations on European Union states to maintain populations of naturally occurring wild birds at levels corresponding to ecological requirements, to regulate trade in birds, to limit hunting of species able to sustain exploitation, and to prohibit certain methods of capture and killing. |
| | **Other PA-related regional agreements entailing park establishment.** Biogenetic Reserves (Council of Europe); Specially Protected Areas of Mediterranean Importance (Barcelona Convention); Special Areas for Conservation (EC Habitats Directive), Baltic Sea Protected Areas (Helsinki Convention), Association of Southeast Asian Nations (ASEAN) Heritage Parks and Reserves (ASEAN Declaration on Heritage Parks and Reserves). |

through the Barcelona Convention (1976), which designates Specially Protected Areas of Mediterranean Interest (www.rac-spa.org).

Protected area coverage varies greatly by nation. Within individual countries, areas may be designated for federal, state, or local protection with varying objectives. In the United States, for example, Nature Reserves, Wilderness Areas, National Parks, Natural Monuments, Species Management Seascapes, and Areas Managed for Sustainable Use together protect about 15.8 % of the total land area (World Resources Institute 2003, based on data from UNEP-WCMC 2003). For more information about the different types of PAs worldwide, please see Table 1, or consult the World Database on Protected Areas (http://sea.unep-wcmc.org/wdbpa/unlist).

Reserves can be managed by governments, private entities, communities, or through cooperative arrangements. To learn more about the governance, effectiveness, and human aspects of PAs, please see our companion NCEP module *Protected areas and Biodiversity Conservation II: Management and Effectiveness*.

## Protected Area Objectives

Biodiversity conservation is one major objective in protected area planning, and is the main focus of this module. An essential role of PAs is protecting biodiversity from extinction or threats. Protected areas may be implemented to conserve populations, species, or genetic diversity. They can protect habitats at *community, ecosystem*, *landscape*, *biogeographic*, and ecoregional scales, and safeguard vital *ecological processes*. PAs may also be designed to act as buffers against anthropogenic or natural uncertainty, including catastrophes and climate change.

Many parks are established for purposes other than protecting biodiversity. Parks have been chosen to protect *features of special interest*, such as water or scenery. Alternately, the goal of biological conservation can be coupled with diverse aims. Common *sustainable use* objectives include provision of *ecosystem services,* such as clean water and carbon sinks, and extraction of biological resources for subsistence or commercial use. Extractive Reserves in Brazil are one particularly well-known example, although there are others, where conservation and development are combined goals. These reserves were initially proposed by The Rubber Tapper's National Council, led by Chico Mendes until his widely condemned assassination (Ruiz-Perez et al., 2005). *Separation of conflicting activities* is the goal of the "Parks for Peace" initiative, which employs *transboundary reserves* as a tool in conflict resolution (IUCN, 2003). Protecting *cultural heritage* and *indigenous peoples, alleviating poverty*, and providing *recreation*, *education* and *spiritual benefits* are additional goals of PAs. Increasingly, parks are being designed to achieve multiple objectives and take the needs of stakeholders into account (see NCEP module *Protected Areas and Biodiversity Conservation II: Management and Effectiveness*).

### IUCN Categories

The IUCN has defined six categories of terrestrial and marine protected areas according to management objectives (IUCN, 1994). They range from **Category I,** aimed mainly at biodiversity conservation, to Category VI, managed principally for sustainable resource use (Table 2). In the global PA system, different categories of reserves are unequally represented in size and number, with smaller and less strict areas being more common (Chape et al., 2005). The IUCN categories were originally developed as a 'common language', to help communications and reporting about PAs. These categories serve the useful and needed function of standardizing designations that may vary by country, improving communication and enabling comparisons. The categorization further aims to help protected area agencies plan their systems, by describing a suite of different management approaches, and also more generally to publicize the importance and diversity of PAs.

IUCN and other organizations supported the two-year 'Speaking a Common Language' (SaCL) project to: 1) evaluate the impacts and effectiveness of the 1994 IUCN category system; and 2) examine what needs to be done to refine and promote the objectives-based PA categorization. Overall, the project has reaffirmed the conservation values and impor-

| Table 2. IUCN Categories of Protected Areas | |
|---|---|
| **Category Ia** | Strict Nature Reserve: protected area managed mainly for science. |
| **Category Ib** | Wilderness Area: protected area managed mainly for wilderness protection. |
| **Category II** | National Park: protected area managed mainly for ecosystem protection and recreation. |
| **Category III** | Natural Monument: protected area managed mainly for conservation of specific natural features. |
| **Category IV** | Habitat/Species Management Area: protected area managed mainly for conservation through management intervention. |
| **Category V** | Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation and recreation. |
| **Category VI** | Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems. |

(Source: Modified from "http://www.unep- wcmc.org/protected_areas/categories/)

tance of the 1994 system. In some countries such as Australia, it has been relatively successful. However, the categories have been less well understood in other states.

A number of issues were found to warrant further clarification (Bishop et al., 2004):

1. It is not clear how to classify large PAs containing a range of *zones*, each with different management objectives;
2. Application of the category system in certain *biomes*, such as forest or marine areas, has proven problematic. This issue is especially acute in large marine protected areas where ecosystem scale management is sought;
3. Where one protected area lies within another (e.g. a strict reserve exists within broader landscape or seascape categories), each with its own category, 'double counting' may occur: for example, in the United Kingdom, some Category IV nature reserves are nested within Category V national parks; and
4. There is also some confusion about how to report transboundary protected areas. The SaCL project identified a number of potential improvements in the interpretation and the application of this system, and suggested the need to develop an updated edition of the 1994 guidelines to the category system (Bishop et al., 2004; NCEP module *Protected Areas and Biodiversity Conservation II: Management and Effectiveness*).

More recently, questions have been raised about the interpretation of the IUCN PA definition, the relative importance and necessity of protecting biodiversity in PAs as an objective, issues of balancing reserves of different categories, and IUCN roles in governmental use of these categories (see NCEP module *Protected Areas and Biodiversity Conservation II: Management and Effectiveness*).

**PA Networks**

Separate protected areas can be linked into a network unified by common goals, shared management, and/or biophysical connections. Networks can be designed to increase the biogeographic representation of habitats and area of coverage. They can also be created to preserve key linkages, maintain genetic diversity, and as a buffer against environmental variation. In the marine realm, PA networks commonly consist of individual sites connected by *dispersal* or migration of marine organisms, ocean currents, or ecosystem processes (NAS, 2001). The conservation value of a network is often greater than if each PA were ecologically isolated. Linking reserves into networks can expand the potential of individual sites to achieve diverse management objectives over a broader area. This also accommodates competing interests and socioeconomic constraints, facilitates enforcement, and precludes all reserves in a country from being no-take. Brazil's National System of Nature Conservation Units (SNUC) is an example

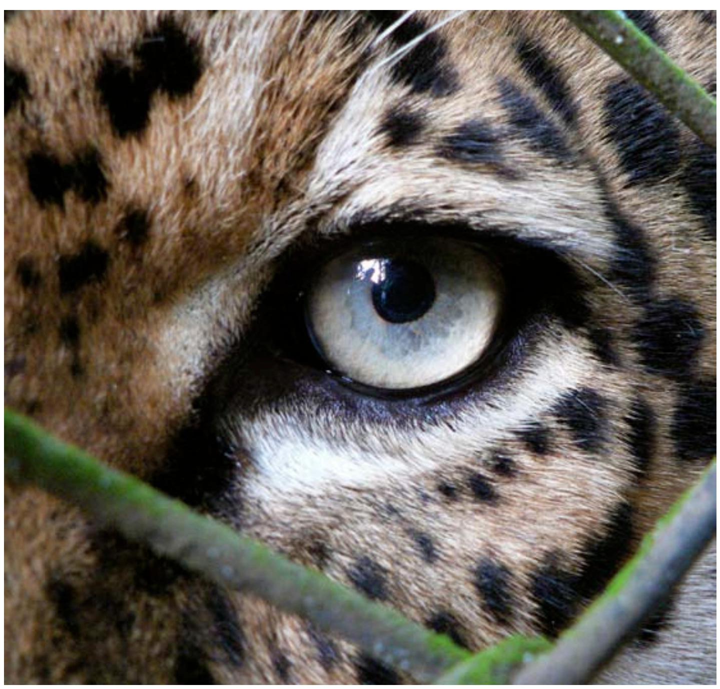
**Box 1. A Transboundary Protected Area Network**

The proposed El Condor-Kutuku Conservation *Corridor* is an innovative transboundary network that includes-PAs of various IUCN categories. Located in long-contested areas in the "Cordillera del Condor " mountain range along the border of Peru and Ecuador, the initial project was conceived as a means of attaining cooperation and minimizing disputes. In the late 1990's, adjacent PAs were established on both sides of the border: the "El Condor Park" in Ecuador and the "Zone of Ecological Protection" and "Santiago-Comaina Reserved Zone" in Peru. The cross-boundary effort enabled protection of endangered, endemic, and migratory species, as well as ecosystem processes, while furthering peace through cooperation on conservation and sustainable development initiatives (Ponce and Ghersi, 2005).

of a national effort to protect threatened and biologically diverse areas (Silva, 2005), and international PA networks (Box 1) can also be effective.

### Surrogates for Reserve Selection

Many parks are designed to conserve specific threatened organisms. Sites may be chosen to protect taxa listed on the IUCN Red List, which includes species at risk of extinction (http://www.redlist.org). Focal species may also be used as surrogates, or tools, to conserve other groups and ecosystems as well. Charismatic taxa may serve as *flagship species*, garnering public attention and support that can then be used to protect their ecosystems (Caro and Doherty, 1999). These flagship species are often charismatic mega-vertebrates, such as jaguars, that attract public support (see NCEP module *The Management of Conservation Breeding Programs in Zoos and Aquariums*). In Belize, for example, the Cockscomb Basin area was set aside as a Jaguar Preserve and a wildlife sanctuary. Another option is to focus protection on *indicator species*, or "organism[s] whose characteristics (e.g., presence or absence, population density, dispersion, reproductive success) are used as an index of attributes too difficult, inconvenient, or expensive to measure for other species or environmental conditions of interest" (Landres et al., 1988). Protection of communities or habitats can also be achieved by conserving *umbrella species*. These are organisms, such as migratory wildebeest (*Connochaetes taurinus*), whose habitat requirements and range also encompass the needs of other conservation targets (Caro and Doherty, 1999). Multiple species are likely to serve as better "umbrellas" than individual taxa (Lambeck, 1997). PAs may also be designed to protect organisms that are important to ecosystems. *Keystone species* such as figs (Moraceae), mast-fruiting dipterocarps (Dipterocarpaceae) in Asia, or habitat-forming organisms like corals, have



The Jaguar, *panthera onca*, is a flagship species for the conservation of its habitat in the Amazon (Source: F. Laso )

**Box 2. Convention on Wetlands of International Importance (Ramsar)**

The Convention on Wetlands of International Importance (Ramsar, Iran, 1971) addresses the conservation of exceptional and/or threatened wetland habitats and sites. Wetlands are defined by the Convention as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres"… and "may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands", as well as human-made wetlands (www.ramsar.org). The Ramsar Convention provides a framework for the protection and responsible use of wetlands at national and international levels. It places general obligations on contracting Parties, or signatory states, relating to the conservation of wetlands throughout their territories, with special emphasis on wetlands of the List of Wetlands of International Importance. Ramsar was signed in Iran in 1971, and entered into force in 1975. Currently, there are 153 contracting parties to the Convention, which covers 1629 wetland sites protecting about 1,456,204 km2 (www.ramsar.org). For additional information on other treaties, please see Table 1 and the NCEP module *International Treaties for Marine Conservation and Management*.

important ecological roles that are greater than would be expected based on their abundance (see NCEP module *Why is Biodiversity Important?*; Caro and Doherty, 1999). A related but different concept is that of *landscape species* such as forest elephants, which "use large, ecologically diverse areas and often have significant impacts on the structure and function of natural ecosystems" (Redford et al., 2000). Conservation of these organisms aims to protect additional species and habitats, however in this case the species' requirements are employed to define the target conservation landscape (Sanderson et al., 2002). Landscape species are sensitive and susceptible to human impacts, and use of multiple taxa may enhance effectiveness of this strategy (Copolillo et al., 2004).

**Reserves to Protect Specific Habitats**

Certain habitats with exceptional characteristics and/or threats may be chosen for protection in PAs. Coral reefs, the rocky intertidal, mudflats, seagrass beds, and wetlands (Box 2) can be considered at-risk marine systems worthy of conservation in PAs (Airame et al., 2003). Significant natural communities, for example pine barrens, freshwater tidal marshes, floodplain forests, chestnut oak forests, and talus cave communities in New York (Howard et al., 2002), may be chosen for protection in reserves. Site choice may be based on habitat characteristics, including substrates, such as hard or soft sediments, and coastline features, for example sandy beach or rocky coast (Airame et al., 2003). Depending on data availability and scale, aspects of species distributions and demography, such as abundance, distribution, and population growth, are also considered in selecting habitats for protection (see Airame et al., 2003). In the absence of reliable comprehensive data, environmental, climatic or physiographic surrogates such as rainfall, temperature, and vegetation structure can be employed. It is important to consider how well selected sites represent the spatial area and resources used by a community of species.

**Reserves to Protect Ecological Processes**

Maintaining or restoring *ecological processes* or *ecosystem functionality* are important considerations in conservation planning. Ecological processes, such as streamflow, floodplain, fire, and erosion processes, are those that create, build, or shape habitats and systems. Maintaining community-level interactions, such as between producers and consumers or partners in mutualism, and addressing natural levels of disturbance, are key elements of an ecological approach to foster natural processes and change in a reserve (Scott and Csuti, 1997). Protection of an area of appropriate size and shape, as well as adequate number of individuals, is important for population

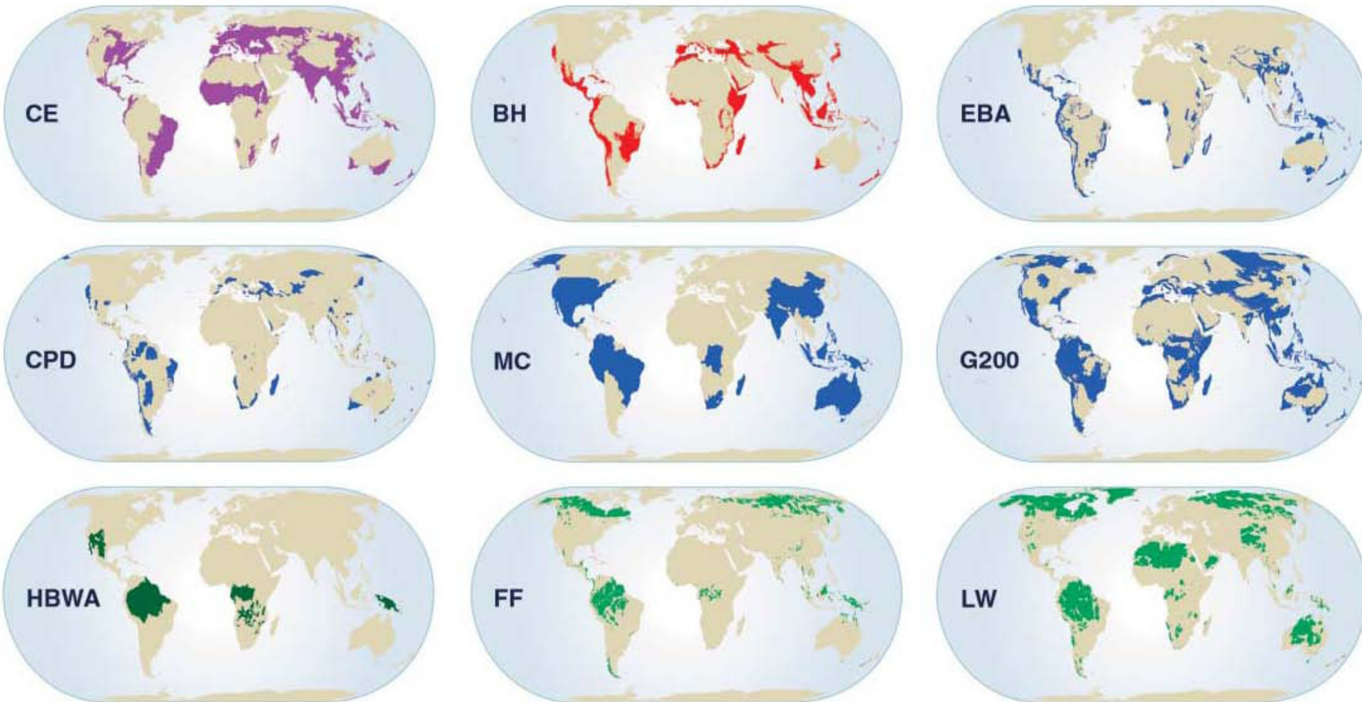



Figure 1. Maps of the nine global biodiversity conservation priority templates: CE, crisis ecoregions; BH, biodiversity hot spots; EBA, endemic bird areas; CPD, centers of plant diversity; MC, megadiversity countries; G200, Global 200 ecoregions; HBWA, high-biodiversity wilderness areas; FF, frontier forests; LW, last of the wild. (Source: Brooks et al., 2006)

viability. Large PAs may be required to maintain metapopulation dynamics, preserve intact and/or functioning ecosystems, and to accommodate wide-ranging species.

### Areas of High Taxanomic Diversity

Priority areas may be selected to preserve *species richness* or *species diversity*. Species richness refers to the number of species present at a site, while species diversity is the species number weighted by an indicator of abundance, for example population size or biomass (see also NCEP module *What is Biodiversity?*). Conservation priorities can be based on abundance, rarity, threat levels, *phylogenetic* or *evolutionary distinctiveness*, the extent to which assemblages represent regional diversity, or *endemism*. Combinations of these criteria are also employed; for example, conservation planners are increasingly interested in taxonomically rich and threatened sites that could be chosen to maximize cost-effectiveness. Concentrated, long-term and careful effort focused on such high priority areas may ensure that a large proportion of the world's biodiversity will escape extinction.

Currently, there are several global conservation priority-setting methods based on species distributions, threat levels, and financial considerations (Figure 1; reviewed by Brooks et al., 2006). These approaches tend to focus on irreplaceability, targeting areas with highly diverse and endemic plant, bird, or terrestrial vertebrate taxa. *Biodiversity Hotspots* have been identified that occupy only one to two percent of the earth's land surface, but are the exclusive home of one fifth of the world's plant species (www.conservation.org; Myers et al., 2000; Sechrest et al., 2002). Sites were designated terrestrial biodiversity hotspots if they contained at least 0.5 percent of the world's plant species and had lost at least 70 percent of their primary vegetation. The resulting 25 hotspots are home to 20 percent of the world's human population (IUCN,

2003), and on average 10 percent of these hotspots are a part of protected areas.

Some of these priority-setting approaches are considered proactive, focusing on sites with low threat but high irreplaceability, and others are reactive, prioritizing both threat and irreplaceability (Brooks et al., 2006). One example of a reactive approach is the Wildlife Conservation Society's (WCS) *Last Wild Places* (Sanderson et al., 2002). Last Wild Places are identified using biodiversity indices in combination with threat indicators, such as human population density, accessibility of the regions to human development, and land transformation (Sanderson et al., 2002).

For some purposes, the level at which conservation priority areas are defined may be too coarse for effective conservation planning, possibly failing to capture finer-scale variation (Olson et al., 2001). The entire Caribbean, for example, is considered one Biodiversity Hotspot (Myers et al., 2000). To address this, a hierarchical approach may be employed whereby smaller sites are evaluated for protection, sometimes within these larger areas. The World Wildlife Fund (WWF), for example, focuses on priority "*ecoregions*" (www.wwf.org; Olson et al. 2001). An ecoregion is "a large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions" (www.wwf.org). The *Global 200 Ecoregions* are the subset of terrestrial and aquatic ecoregions with exceptional biodiversity and ecosystem representation that are considered high priorities for conservation (Figure 1; http://assets.panda.org/downloads/ecoregions_map.jpg; Olson and Dinerstein, 2002). Recently, the WWF selected 19 Priority Places, including the Amazon rainforest, the Galapagos, the Congo Basin, the Coral Triangle, and Madagascar, of top conservation priority (www.wwf.org).

*Methodological Limitations of Priority-Setting Exercises*

Although such exercises are promising, it is important to consider their methodological limitations (reviewed in Brooks et al., 2006). One contentious issue is the difficulty in measuring taxonomic richness (Pimm and Lawton, 1998). Quantifying biodiversity requires expensive, expert inventories that are often not feasible (Howard et al., 1998). In practice, selected indicator groups, such as vascular plants, birds and butterflies, are assessed. Pimm and Lawton (1998) question how well patterns coincide between indicators and other elements of biodiversity. A site that contains many plant species, for example, may not be rich in other taxa, or contain rare organisms. Prendergast et al. (1993) found limited spatial congruence between taxonomic groups in Great Britain: areas rich for one taxon, such as butterflies, were not hotspots for others, such as birds. Similar limited overlap is reported for temperate and tropical areas (Kerr, 1997; Howard et al., 1998). Another controversial question pertains to which criteria are best suited to define hotspots. A comprehensive global study of birds assessed overlap of different hotspots defined by species richness, threat, or endemism, and found only limited congruence (Orme et al., 2005). In another approach, many rare species were found in "cold spots," sites of relatively low biological diversity that harbor threatened or uncommon ecosystems or species (Kareiva and Marvier, 2003). The additional question of source-*sink*, dynamics was raised by Hansen and Rotella (2002). A sink population requires net immigration to sustain itself. These individuals may come from a source population, characterized by net emigration. Protecting areas that are sinks, despite apparent abundance, may be counterproductive if the sources are threatened.

In reviewing the different priority setting methods, Brooks et al., (2006) acknowledge many of these issues, while emphasizing the importance of worldwide conservation planning to determine how financial resources should best be channeled. There are overlapping areas, such as in the tropics, identified in many of these distinct efforts, and Brooks et al. (2006) suggest these as promising initial recipients of global donor funds. The authors further highlight the need to focus conservation prioritization efforts at increasingly finer spatial scales, such as at the level of sites where PAs can be established.

**Representation**

Sites may be selected for protection because they are represen-

tative of biodiversity. Analyses of the global protected area system have been carried out to determine to what extent biodiversity targets are currently represented, and where new PAs should be established to achieve representative coverage (Box 3, Brooks et al., 2004; Box 11, Rodrigues et al., 2004a; 2004b). Although many land biomes and habitats are included in this system, others, such as lake systems and temperate grasslands, are not well represented (Box 3; Brooks et al., 2004). Over 90 percent of the existing parks are terrestrial, with MPAs protecting only 0.5 percent of the world's oceans. The largest nationally designated PA in the world is the North-East Greenland National Park, a site measuring 972,000 km2 and covered in large part by snow (UNEP-WCMC, 2003). In the United States, most of the productive and low elevation land is privately owned, so that many habitats and species occur outside of reserves (Scott et al., 2001). In a study of terrestrial vertebrates, 12 percent of species were not found in parks (Rodrigues et al., 2004a; Box 11).

In 1992, the Fourth World Congress on National Parks and Protected Areas, held in Caracas, Venezuela, established a target for conserving biodiversity by recommending "that protected areas cover at least 10 percent of each biome by the year 2000" (McNeely 1993). This target has been generalized to apply to individual countries and to the entire planet, and is commonly referred to as "the 10 percent rule". However, since biodiversity is not evenly distributed worldwide, the scientific basis and conservation value of uniform targets based on the percentage of the planet or its biomes that is protected have been questioned (Soule and Sanjayan 1998; Pressey et al., 2003). Contrary to frequent recommendations, current protection levels should not be used as a significant criterion to guide priorities for allocation of future conservation investments, as the percentage of area already protected in a given country or biome is a very poor indicator of additional conservation needs.

There are two broad emergent issues in PA design related to representation: 1) The global protected area system is far from representative, and filling the gaps in the existing system should be a high priority for conservation (Box 3; Box 11); 2) The percentage of the planet or its biomes that is protected is less important than PA location and management. Overall, uniform targets based on the percentage of area protected cannot be used to distinguish between regions that are sufficiently protected, and those that need additional conservation.

### Climate Change

Protected areas may be planned to serve as buffers against unpredictable or catastrophic events. Climate change has been identified as an important emerging issue for protected area planning (Lemieux and Scott, 2005). Over the past 100 years, the global average temperature has increased, and is projected to continue to rise at a rapid rate. Although species have re-

**Box 3. Representativeness of the Global PA Network**

Twelve percent of the planet is protected in reserves, but is this network representative? Brooks et al. (2004) summarized protected area coverage across each of the terrestrial biomes and biogeographic *realms* to identify bioregional gaps in the global PA network. Temperate conifer forests (25%), flooded grasslands and savannas (18%), and tropical or subtropical moist broadleaf forests (18%) are the most protected biomes. However, if only PAs in IUCN categories I through IV (Table 2) are considered, tundra (12%) emerges as the most protected biome. Temperate grasslands, savannas, and shrublands (5%), Mediterranean forests, woodland and scrub (6%) and tropical or subtropical conifer forest (6%) are the least protected biomes. Protection also varies among biogeographic realms. In relation to total area, habitat protection has been most substantial in the Neotropical (16%), Nearctic (16%), and Afrotropic (15%) realms, but less so in the Indo-Malay (10%), Palearctic (9%), Australasian (8%) and Oceanian (8%) realms.

sponded to climatic changes throughout their evolutionary history, a primary concern for wild species and their ecosystems today is the rapid rate of change. The synergism of rapid temperature rise and other stresses, in particular habitat destruction, could easily disrupt the connectedness among groups, potentially leading to a reformulation of species communities, and to numerous extirpations and possibly extinctions (Peters and Darling, 1985; Root et al., 2003). In many regions, in addition to climate change, human populations and the resulting pressures on ecosystems will continue to evolve, often in ways unfavorable to biodiversity. The interactions between these multiple changes will ultimately have major implications for conservation and protected area planning.

As climate changes, species might move into or out of parks and reserves, likely altering the species composition of PAs, with important implications for conservation (Peters and Darling, 1985). Recently, shifting range boundaries as a result of contemporary climate change have been observed for multiple species, underscoring the potential for climate change effects on species composition at fixed geographical points such as protected areas (Parmesan and Yohe, 2003; Root et al., 2003). It is likely that the amount of range under protection in PAs will change, depending on the new species' occurrence relative to the geographic location of PAs. Overall, the present ranges and the present degree of protection of many species will likely rapidly erode as a result of climate change. Many studies use bioclimatic models to calculate the effect of climate change on species representation in protected areas (Box 4).

**Box 4. Modeling Effects of Climate Change in PAs**

Current and future modeled ranges may be used to calculate the area of a species' range under protection at a given time, keeping in mind that a species' modeled potential range may not precisely match its actual range (Pearson and Dawson, 2003).

In a study based in the Cape Floristic Region of South Africa, Hannah et al., (2005) show that a substantial number of species may lose all suitable range if climate changes. Many species may lose all representation in PAs as a result, while a much larger number may experience major loss in the amount of their range that is protected. The spatial distribution of PAs, particularly between lowlands and uplands, is an important determinant of the likely conservation consequences of climate change.

A study by Lemieux and Scott (2005) examined potential impacts of climate change in Canada's protected area network, which consists of 2,979 PAs. Their vegetation-modeling results project that 37 to 48 percent of Canada's reserves could experience a change in terrestrial biome type under doubled atmospheric carbon dioxide conditions.

In another study, Tellez-Valdes and Davila-Aranda (2003) examined the effects of climate change on the future distribution patterns of 20 species of Cacti in a protected area of Mexico. They used a floristic database and a bioclimatic modeling approach to examine 19 climatic parameters, and to obtain the current potential distribution pattern of each species. Their main findings include a drastic distribution contraction in which most of the remaining populations will inhabit restricted areas outside of reserve boundaries or will become extinct.

In a fourth study, Thomas et al., (2004) model species-distribution responses to a range of climate-warming scenarios, and use a novel application of the species–area relationship. They estimate that 15 to 37percent of modeled species in various regions of the world will be committed to extinction by 2050.

**Box 5. The Biological Dynamics of Forest Fragments Project**

This seminal empirical reserve design study is a classic example of how Island Biogeography Theory has been applied to conservation. The project stemmed from Thomas E. Lovejoy's idea to research forest fragmentation in the Brazilian Amazon, where landowners were required by law to maintain forests on half of their property. Within an area planned for cattle ranching, plots of various sizes and degrees of isolation were designed to assess dynamics of forest fragments, mostly in the early 1980's (Bierregaard Jr. et al., 2001). Major findings included the generally negative effects of land fragmentation, isolation, and small patch size on many species over time. To minimize harmful effects of fragmentation, it was suggested that roads be avoided, simple land-use guidelines be employed throughout the deforestation process, and that the human context of deforestation be considered in planning conservation strategies (Bierregaard Jr. et al., 2001; NCEP module *Ecosystem Fragmentation and Loss*).

## Designing Reserves for Biodiversity Conservation

Once PA objectives have been defined, a subsequent step in the systematic planning process is reserve design. This encompasses size, shape, *replication,* complementarity, and connectivity of PAs. The Theory of Island Biogeography, developed initially for true oceanic islands (MacArthur and Wilson, 1967), has substantially impacted PA design especially as regards reserve size and connectivity (Box 5). The theory postulates that, as the area of an island becomes larger, the number of species increases, while extinction rates decrease. The number of species results from a balance between the colonization rate of new taxa, and the extinction rate of resident groups. The number of species tends to decline in fragmented or isolated habitats, as immigration rates are lowered due to barriers, and extinction rates tend to increase as areas diminish.

### Size

Heated debates over optimal PA size permeated the literature of the mid-1970's, dwindling by the mid-80's (Soulé and Simberloff, 1986; Bierregaard et al., 2001). Controversy centered on the benefits of "**S**ingle **L**arge **O**r **S**everal **S**mall" parks, commonly referred to as SLOSS. Given limited resources, should we choose one large reserve or several small ones of the same total size? SLOSS is currently less of a point of argument, partly because the answer depends on the context, and partly because political and fiscal realities, rather than ecological models, often determine reserve size - today, about 60% of PAs are smaller than 100 km2 (Chape et al., 2003).

Larger parks are typically advantageous because contiguous areas are often better able to preserve intact communities of interdependent taxa and maintain viable populations of species that occur at low population densities, especially large vertebrates. Large PAs tend to include more organisms and generally house a greater diversity of species and habitats than individual small reserves. Larger PAs can also accommodate population growth, and support bigger groups in which the deleterious effects of small populations are countered. These harmful factors include inbreeding, loss of genetic diversity, and increased extinction risk (see NCEP module *Small Population Phenomena*). In western North American parks, for example, an inverse relationship between mammal extinction rates and park area, consistent with Island Biogeography Theory, was revealed (Newmark, 1995). The negative effects of environmental disturbance and catastrophes may be buffered in large areas. These may also be better able to support functioning ecosystems and accommodate shifts in species distributions caused by processes such as climate change. Large sites may be required to maintain meta-population dynamics and accommodate wide-ranging or low-density species.

A system containing several small PAs, on the other hand, also provides many benefits such as increased representation,

The shape, size, and degree of fragmetation/isolation of a forest patch restricts which species may inhabit it (Source: K. Frey)

replication, and feasibility. Multiple reserves are recommended to buffer against uncertainty and catastrophe, and replication of sites may be more feasible in a network of small parks. It may be possible to conserve a greater variety of taxa, including endemic species, in a system of small reserves that protects multiple heterogeneous ecosystems, than in a single large reserve (Soulé and Simberloff, 1986). This is true even though each individual small area may contain fewer species. Importantly, small sites may be sufficient to protect certain target species with small ranges, such as plants, small mammals, and insects. In fact, some groups characterized by low dispersal, such as amphibians and mollusks, naturally occur in small, isolated populations.

There is no single answer to the SLOSS debate, as optimal park size will vary depending on organismal and habitat characteristics, and what constitutes a small or large reserve can depend on the circumstances. Many current approaches to reserve size choice are therefore goal-based. A combination strategy, in which large PAs maintain functional ecosystems and large-scale processes, while small reserves protect rare elements such as certain species, may work best. This is the essence of the "coarse filter-fine filter" strategy advocated by The Nature Conservancy. In a "course filter" approach, many species are automatically conserved as a result of protecting their ecosystems. However, some taxa are not necessarily conserved in this approach, requiring a complementary "fine-filter" strategy targeted to their specific needs.

**Box 6. Edge Effects of Eurasian Badgers in Spain**

Carnivores such as the Eurasian Badger (*Meles meles*) are particularly vulnerable to anthropogenic edge effects such as road kills, hunting, poaching, or incidental trapping (Revilla et al., 2001). These badgers were monitored using radio telemetry to study edge effects at the Doñana National Park, Spain. This reserve was chosen because of its extensive biological diversity, its geographic location, and historical preservation from development as a game preserve. Causes and rates of mortality were studied for two badger populations, one of which occurred near the park border, while the other was further away. The study revealed that most badger mortality (about 85%) was due to poaching and road kills. Of the two populations studied, the one closer to the edge of the park suffered the most mortality, and population density was about three times higher in the interior population. Statistical analyses revealed that distance from the park's boundary affected the likelihood of survival. The researchers therefore concluded that, although reserves are beneficial to the species, their effectiveness is reduced because of the mortality along the edges. Therefore, it was recommended that reserves be enlarged, and human activities contributing to these edge effects be curtailed (Revilla et al., 2001).

### Shape

PAs can be designed in shapes that maximize compactness, minimizing boundary length (Andelman et al., 1999). This is desirable to counter potentially harmful "*edge* effects", the physical, biological, synergistic, or anthropogenic (Box 6) processes that occur in edge environments. Edges are border areas, or ecotones, that mark the transition between two different habitats (see NCEP module *Ecosystem Loss and Fragmentation*). Edge effects can include alterations in microclimate, species composition, abundance, and distribution, and species interactions such as predation and competition (Matlack and Litvaitis 1999; NCEP module *Ecosystem Loss and Fragmentation*). Biodiversity and habitat quality may be negatively affected in these areas, and extinction has been linked to edge effects at park borders, especially for wide-ranging species (Woodroffe and Ginsberg, 1998). Although edge environments may be beneficial to invasive or certain generalist species, a general PA design principle is to avoid them because of their generally harmful effects on conservation targets. Therefore, because edge effects tend to be more extensive in areas where the perimeter to area ratio is higher, such as in reserves of elongated shape, and lessened in areas of rounder shape, the latter may be favored in reserve design.

### Replication

An important design criterion is to represent key features more than once. Multiple representation of species or ecosystems in reserves safeguards conservation targets from environmental change and catastrophic stochastic events, such as storms, hurricanes, fire, and oil spills, that could destroy the last remaining site or population. Most Kemp's Ridley sea turtles (*Lepidochelys kempii*), for example, nest at a single site in Rancho Nuevo, Mexico. This species is thus considered highly vulnerable to extinction due to the severe consequences to the species if any natural or human disturbance affects that breeding colony. Efforts were therefore undertaken to establish a companion nesting beach at the Padre Island National Seashore, Texas, USA (Shaver, 1989). Replication is also important for assessment purposes, providing increased sample sizes and lowering the potential for analytical error due to over-reliance on any one site. Human use of protected areas also supports replication as a design principle. If, for example,

**Box 7. Complementary Reserve Systems in Africa**

The forest reserve network in Uganda was planned to maximize habitat and species representation through complementarity. By alternately adding sites, it was possible to design a network capable of protecting about 96 percent of indicator groups. Despite the limited spatial overlap in species richness of butterflies, moths, and plants, sets of complementary forests chosen using one indicator taxon generally represented the species richness of other groups as well (Howard et al., 1998; 2000).

In South Africa, however, low congruence was detected in complementary networks selected for different taxa, such as birds and mammals, as well as butterflies, plants, and various other invertebrates (Van Jaarsveld et al., 1998). Neither did complementary networks there overlap with areas of high and/or low species richness, species rarity, or indicator species.

Although complementary networks and use of indicators may be promising if, for example, most organisms share similar biogeographical patterns (i.e. large numbers of species are restricted to northern or southern sites (Pimm and Lawton, 1998; Howard et al., 1998), they are not representative in all cases. Therefore, PA networks designed to be complementary should probably include multiple species and the full range of available or necessary data, unless evidence indicates that indicator species capture patterns of overall diversity and threats.

people heavily use one particular habitat, such as a lakeshore, protection of additional similar sites may alleviate harmful anthropogenic effects.

**Complementarity**

Conserving groups of sites selected to maximize complementary species distributions or habitats is a promising strategy for increasing overall representation (Howard et al., 1998; Howard et al., 2000). Complementarity is measured as the extent to which a reserve advances the goal of representing biodiversity in a network, by contributing unique elements. Networks are designed so that targets, such as species, absent at one site are present at another, thus resulting in a set that together (rather than individually) maximizes species richness. The process involves selecting the area with the highest species diversity (or other selected criterion), then discounting groups present there in the choice of the next most species-rich area, for example, and so on (Brooks et al., 2001). Complementarity has been applied at continental and national levels in Africa (Box 7; Howard et al., 1998; 2000; Brooks et al., 2001).

**Isolation and Connectivity**

Dispersal and migration are processes that connect populations. Movement is often a natural part of organismal development, such as dispersal from nursery grounds to feeding areas, and finally to breeding sites. Daily movements, annual migrations, and range shifts in response to climate change are additional kinds of movements. In addition, certain groups may constitute a metapopulation, in which some areas are "sources" of dispersing individuals, while others are "sinks" characterized by net immigration or mortality.

Natural patterns of dispersal and migration are increasingly disrupted, and protected areas are a promising way of countering fragmentation and ensuring population connectivity. Fragmentation, for instance caused by roads in a terrestrial environment, can directly cause mortality and block access to sites essential for different phases of organismal life cycles. Disruption of movement may be especially harmful when groups become small and isolated (see NCEP module *Biology of Small Populations*). Therefore, maintaining natural linkages among populations is an important consideration in reserve design. Considering the movements of organisms throughout their life cycles is necessary to ensure that reserves are placed to protect connections and all stages of development. Protecting sources is desirable for their contribution to population structure and abundance. Sinks, on the other hand, are potential candidates for sustainable resource extraction.

A common application of PA networks is using multiple reserves as stepping-stones for wide-ranging and migratory species, such as butterflies (Schultz, 1998). Genetic analysis of historical and contemporary red squirrels, for example, revealed that gene flow occurred between patches of pine forest in Great Britain (Hale et al., 2001). A stepping-stone approach, however, may be challenging for whales and other highly migratory species in which home ranges are vast, with much of the life cycle spent in unprotected high seas. To protect such species, PAs can be located in sites essential to their life cycles, such as nursery or breeding grounds. For some organisms, species-level legal protection might be necessary (see NCEP module *Endangered Species Management*). Other tools available include integrating areas outside the PA system into landscape-level planning for conservation (see NCEP module *Protected Areas and Biodiversity Conservation II: Management and Effectiveness*), or using corridors.

There has been much debate about the use of *corridors*, or protected strips of land designed to connect otherwise isolated habitat fragments (Hobbs, 1992; Beier and Noss, 1998). Joining separate areas using corridors may allow movement of organisms among habitats, potentially resulting in genetic exchange, increased species diversity, and interactions between taxa (Tewksbury et al., 2002). Corridors in fragmented pine forests, for example, facilitate plant-animal interactions (Tewksbury et al., 2002), as well as dispersal of birds, butterflies, and small mammals (Haddad et al., 2003). However at this stage, the corridor concept is more theoretical than

| Table 3. Zoning in Marine Protected Areas | | | | |
|---|---|---|---|---|
| **Zone** | **Synonyms** | **Activities Allowed** | **Activities Prohibited** | **Purposes** |
| **Marine Reserve** | No-take, no-access | Limited | Take, access | Counter harmful processes; address conservation and fishery management objectives; provide insurance against management failure (NAS 2001; Agardy 2000). |
| **Restricted Access** | Sanctuaries, no-take areas | Limited public activity, such as swimming, diving, and ecotourism | Extraction, take | Meet sustainable use goals, attract public attention and support; household or park income from ecotourism; pride in community involvement; fishery and conservation benefits |
| **General Reserve** | | Regulated access and take; ecotourism, restricted fishing, research, education; recreation | Destructive practices | Address stakeholder interests |
| **Buffer Area** | Traditional use areas; partial reserves | Entry, take | Destructive practices | Buffer between the park and surroundings; potentially capable of protecting core areas from pollutants and other threats; Integrated conservation and development projects (ICDPs), as well as educational and administrative facilities, are often housed in the buffer zone. |

proven in fact. The research results are considered insufficient in scale, taxonomic and ecological comprehensiveness, and susceptible to confounding effects (Hobbs, 1992; Tewksbury et al., 2002). Functional connectivity differs between species, and in some cases corridors have not convincingly enhanced linkages among groups (Haddad and Baum, 1999; Collinge, 2000). Further, corridors may serve as sinks, attracting organisms into edge-dominated, predator-rich areas. They may be of limited utility to some forest organisms, such as sedentary or interior species. Resources invested in corridors could preclude other options, or be better employed elsewhere (Hobbs, 1992). Additional potentially negative impacts include spread of disease, pests, predators, invasive species, or fire (Hobbs, 1992). Even so, the balance of empirical evidence points to effectiveness of corridors in connecting landscapes (Beier and Noss, 1998; Box 8). In the face of uncertainty, maintaining natural habitat structure in the landscape through a monitored approach is advisable. This may include restoring natural links and employing corridors that are as wide as possible.

## Zoning

Zoning is the spatial definition of activities permitted within delimited areas of a PA (Table 3). UNESCO Man and Biosphere reserves (Table 1; URL), for example, may be divided into core and buffer zones, with heavier restrictions on human use placed within the core, and regulated activities allowed in buffer areas (Figure 2). Other major zoning categories include Strict Reserve, Restricted Area, General Reserve, and Multiple-use area (Table 3; NAS, 2001; Villa et al., 2002). Most human activities, such as fishing, boating, and swimming, are not allowed in strict reserves, core areas, or no-take zones. These restricted areas provide refuge for wildlife, and may serve as controls to assess human impacts in other zones (NAS, 2001; Agardy 2000). Conflicting activities, such as extraction and recreation, may be spatially separated using

**Box 8. Large Mammals in African Parks**

Various large mammals, including primates, elephants, carnivores, and ungulates, are protected within parks in Tanzania, Africa. As is common in many other parts of the world, protected areas there are becoming more isolated from each other and from their surroundings as human activities dominate the landscape. These reserves increasingly appear as islands in an otherwise human-dominated landscape. Island Biogeography Theory predicts that species will be lost as isolation increases and area decreases (MacArthur and Wilson, 1967). Using this theory, Newmark (1996) considered extinctions of large mammals in protected areas of Tanzania. As expected, an inverse relationship between extinction rate and park area was revealed, consistent with extinctions resulting to some degree from PA isolation. Corridors of land linking separate parks were proposed as a promising measure for countering these effects (Newmark, 1996).

zoning. In cases where objectives are compatible, zoning a site for more than one use can result in greater geographic coverage than if permitted activities were kept separate. Various pursuits, such as recreation and limited take, may be allowed in some multiple-use areas. Comparative analysis of zones can provide valuable information for research and adaptive management purposes (Agardy, 2000; NAS, 2001). However, there is no consensus regarding optimal zone size and spatial arrangement, and it is challenging to incorporate biological and scientific uncertainty into fixed zoning plans (Carr and Raimondi, 1999; Agardy, 2000; Villa et al., 2002). Zoning can therefore be year-round or seasonal, permanent or temporary. Successful zoning can be used to equitably accommodate divergent user interests and to achieve management objectives flexibly. The Great Barrier Reef Marine Park zoning plan is one of the most representative and comprehensive in the world (Box 9).

### Stakeholders

*Stakeholder* goals have significant impacts on PA planning and implementation, many times overriding biological considerations (see NCEP module *Protected Areas and Biodiversity Conservation II: Management and Effectiveness*). Adequate incorporation of the reserve design factors discussed above is often constrained by socioeconomic and political issues (Pressey, 1994; Prendergast et al., 1999). Human use of areas surrounding parks can greatly influence their effectiveness, and there is no consensus as to how much human activity should be permitted within parks (Western and Wright, 1994; Oates, 1999; Hulme and Murphee, 2001; Terborgh et al., 2002). It is becoming increasingly obvious that the human context of biodiversity conservation must be seriously considered when planning PAs, including comprehensive assessment of legislative, cultural, societal, political, and economic factors.

Setting aside a site as a protected area can result in costs and benefits for the various stakeholders. There are numerous potential benefits to society from conserving biodiversity, including spiritual, educational, recreational, and economic factors (see NCEP module *Why is Biodiversity Important?*). Reserves,

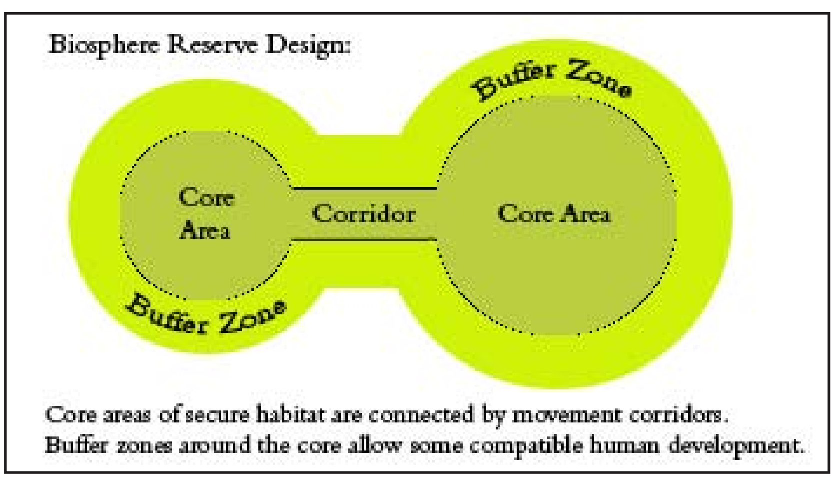



Figure 2. Zoning diagram of reserve design

**Box 9. The Great Barrier Reef Marine Park**

The Great Barrier Reef Marine Park (GBRMP), which is about the size of Japan, is one of the largest and most diverse MPAs in the world. Zoning in the GBRMP is used to achieve biodiversity conservation, fishery management, sustainable use, tourism, shipping, and other goals (NCEP module *Marine Protected Areas and MPA Networks*; Fernandes et al., 2005). Recently, the Park developed a new zoning plan. As a result, about 33 percent of the entire area is now zoned as no-take, enhancing biodiversity conservation (Fernandes et al., 2005). Various activities are allowed in other zones, including boating, diving, photography, and permitted study in the 'Scientific Research' zones, and all of these uses as well as bait netting, crabbing, limited collecting, spear fishing, line fishing, netting, shipping, trawling, and trolling in the 'General Use' zones (www.gbrmpa.gov.au/corp_site/management/zoning). Throughout the re-zoning process, there was extensive communication with and participation of the public, and key reserve planning and design principles from the literature were applied. The new zoning plan, for example, employs strategies to build resilience against possible future effects of climate change by protecting against biodiversity loss and overfishing. At least 20 percent of each bioregion is protected, and a minimum size was established for no-take areas (Fernandes et al., 2005; see also NCEP module *Marine Protected Areas and MPA Networks*). This successful process has resulted in international recognition of the GBRMP and its zoning plan.

for example, are often established to protect resources used by people for hunting or recreation. Often, however, PAs are viewed as impediments or hindrances. It is easier to establish a park in a remote area with few conflicting uses than where land has economic value (Margules and Pressey, 2000). PAs bordering or within areas being developed for tourism, for example, may be viewed as costly by entrepreneurs, due to restrictions on commercial enterprise. Prohibiting activities, such as driving on beaches, may result in a view of PAs as obstacles to recreation. Establishing a strict reserve at a site where resources were previously used may result in loss of income or residence. For additional consideration of these and other points, please see the companion NCEP module *Conserving Biodiversity in Protected Areas II: Management and Effectiveness*.

## Methods of Reserve Selection

*Gap analysis* and *reserve selection algorithms* are prominent methods employed in reserve selection. In gap analysis, a GIS approach is used to identify gaps in existing PA coverage. Alternately or in combination with gap analysis, reserves and networks can be designed using computer algorithms that incorporate biological and socioeconomic factors. These reserve selection algorithms find the minimum area that protects the most diversity, often minimizing the financial cost. These methods can be used singly or in combination, for example by using reserve selection algorithms to design parks in areas identified through Gap Analysis (Pressey and Cowling, 2001). Both methods can incorporate biological and socioeconomic factors, although the full complexity of land ownership, use, and constraints is often not captured (Prendergast et al. 1999). Software and tutorials are available online free of charge, and benefits of using the methods include transparency, clarity, comprehensiveness, and objectivity. Commonly used reserve selection algorithm tools that are freely available include: **SITES** (Andelman et al., 1999; http://www.biogeog.ucsb.edu/projects/tnc/toolbox.html), **MARXAN** (Ball and Possingham, undated; http://www.ecology.uq.edu.au/marxan.htm), and **C-Plan** (http://www.uq.edu.au/~uqmwatts/cplan.html).

In practice, selecting reserves can be a complex process, however these new procedures can provide a planning framework that is helpful in uniting and facilitating communication between different constituencies and agendas. Even so, many reserves to date have been planned through pragmatism, expert knowledge, or participatory approaches, and without refer-

ring to gap analysis or reserve selection algorithms (Pressey, 1994). This may be because theoreticians and conservation planning practitioners do not always communicate (Salafsky et al., 2002). There are also concerns over the feasibility of implementation, as well as the appropriateness of surrogates and the scale of analysis (Prendergast et al., 1999). Necessary resources (time, expensive data collection, a specialist, and computer equipment) may be prohibitive. In a conciliatory approach, analytical results can be used as a starting point for stakeholder and expert conversations (Pressey and Cowling, 2001). Marine PA planning in the Gulf of Mexico, for example, integrated results of the SITES reserve selection software (Andelman et al., 1999; see below) with participant interviews and a workshop (Beck and Odaya, 2001).

**Reserve Selection Algorithms**

Reserve selection algorithms are flexible tools that allow users to test different scenarios and combinations of factors to achieve different goals. When using reserve selection algorithm software, users first enter the relevant data on selected species, habitats, or other biodiversity elements into the program. The sites being considered are divided into planning units, such as hexagons or cells of varying sizes. Care must be taken to select planning units appropriately according to case-specific requirements (Andelman et al., 1999). The minimum area needed to maintain certain species can be entered into these programs, which are also capable of considering the closeness of areas for metapopulation persistence. Outputs can be constrained to minimize size or cost, and to maximize complementarity. Complex programs can minimize boundary lengths to achieve compactness and contiguity, thus decreasing edge. Emphasizing shared boundaries and adjacency can minimize isolation. The risk of catastrophes can be addressed by stipulating a minimum distance separating parks designed to protect the same target. Socioeconomic factors, such as cost and conflict minimization, can also be included. Threats can be incorporated by focusing on endangered species or habitats. Savings may be gained by selecting larger, complementary areas in a PA network, excluding highly priced sites as possible (Ando et al., 1998). Howard et al. (2000) used an iterative algorithm that included biological criteria and minimized opportunity costs and land-use conflicts. Combinations of constraints can be explored as scenarios to assess effects on goal achievement of tweaking different variables. Various solutions are then offered, and users may select their preferred option.

The choice of the best-performing algorithm is case-specific (Pressey et al., 1997). The MARXAN software was designed in response to reserve design needs in the Great Barrier Reef, Australia. Recently, MARXAN was employed to identify priority areas and management strategies for the conservation of 4795 terrestrial mammal species worldwide (Ceballos et al., 2005). Many of these "flagship" species, such as the orangutan (*Pongo pygmeus*), face extinction. The analysis indicated that about 11 percent of terrestrial areas worldwide would need to be protected using various methods to conserve one tenth of the land mammal ranges. A multi-faceted strategy, focusing on existing PAs, establishment of new parks, and management of areas occupied by people, would be necessary to achieve even minimal conservation goals for these taxa (Ceballos et al., 2005). MARXAN's precursor program, SPEXAN, was integrated with ArcView to make SITES (Andelman et al., 1999). Both programs incorporate spatial criteria in site selection and provide decision support for PA design; SITES has a GIS interface. SITES was employed in The Nature Conservancy's ecoregional conservation efforts at the Idaho Batholith and in the Northern Sierra Nevada. The program was also used to design the Channel Islands National Marine Sanctuary (Airamé et al., 2003). C-plan was employed to design a reserve system in the Cape-Floristic region of South Africa (Box 10).

**Gap Analysis**

Gap analysis is a biogeographic approach to biodiversity conservation planning that uses satellite remote sensing and geographic information systems (GIS) to identify and bridge gaps in existing protection efforts (Scott et al., 1993). Gap analysis consists of identifying and classifying the: 1) distribution of biotic communities, such as vegetation cover or natural fea-

**Box 10. Reserve Design in the Cape Floristic Region, South Africa**

One of the best-known examples of the PA planning process is in the Cape Floristic region of South Africa (Balmford, 2003). This area is a Biodiversity Hotspot and a priority Ecoregion, widely recognized for its endangered and endemic plant diversity. A conservation planning program based on the framework of Margules and Pressey (2000) was instituted there, focusing on biodiversity protection, sustainable use, and capacity building. This framework consists of six stages that incorporate feedback and revision. Elements of biodiversity, such as species or vegetation types, are initially chosen as surrogates for overall patterns. Targets and goals for protection of these elements are then defined. In the third stage, the extent to which these goals have been met by existing PAs is determined. In Stage Four, additional sites are selected to achieve the remaining objectives. The final two steps consist of reserve implementation and monitoring (Margules and Pressey, 2000).

Following Margules and Pressey's framework, biological and spatial data about the Cape-Floristic region were obtained, and a comprehensive threat assessment was conducted. Challenges to conservation planning there include agriculture, cattle grazing, urbanization and invasive species. Goals were then defined for short- and long-term persistence of the target elements; specific but mutable targets were devised to conserve species, habitats, and ecological processes. Analyses carried out using the 'C-Plan' program revealed that most of the targets were not

tures. Other important data include elevation, slope, aspect, soils, aquatic features, and climate; 2) biodiversity, such as plant, vertebrate or invertebrate distributions; 3) management regimes and socio-economic considerations for focal areas; 4) biodiversity that is not adequately represented in areas managed for conservation; and 5) priorities for conservation action (Figure 3). Once candidate areas are identified through gap analysis, other principles of conservation biology, such as population viability analysis, ecosystem patch dynamics, complementarity, and habitat quality can be used to select specific sites and determine appropriate management area boundaries.

Figure 3. Gap Analysis (Source: http://libraries.maine.edu/Spatial/gisweb/spatdb/gislis/gi94030.html)

Gap analysis is considered promising for its practicality and simplicity, however there are some limitations. Gap analysis has been useful in identifying ways to improve the global PA network (Box 11), and provides a way of ranking the conservation needs of species and communities. The data layers also furnish information about the context of areas being managed for different values,

**Reserve Design in the Cape Floristic Region, South Africa (Continued)**

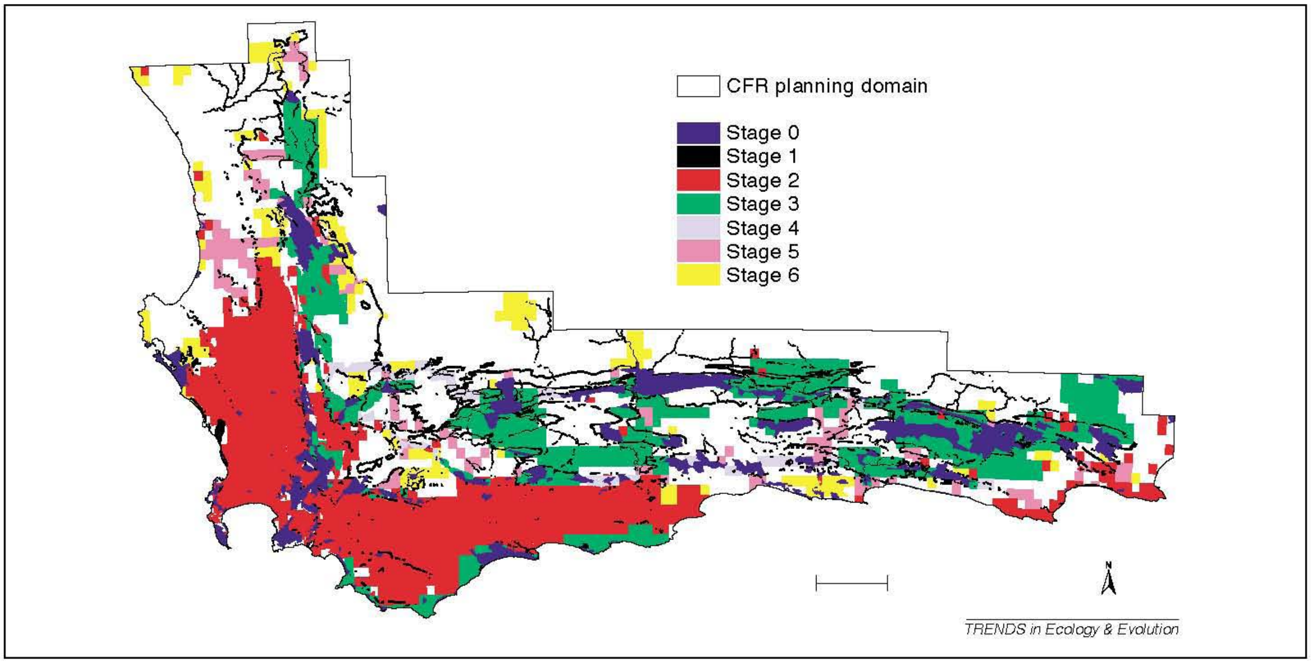



Figure 4. Protected Area Planning in the Cape Floristic Region (Source : Reprinted from Trends in Ecology and Evolution 18(9), Balmford, A., Conservation planning in the real world: South Africa shows the way, 435-438, © 2003, with permission from Elsevier.)

land-use agreements were entered into with private owners. This strategy had the additional benefit of increasing stakeholder involvement and addressing funding limitations. Throughout the process, landowners, government agencies, non-government organizations (NGOs), local communities, and scientists were involved in formulating the conservation plan. The resulting proposed plan included established reserves, and also required that conservation efforts be carried out in over half of the area outside existing parks (Figure 4). Recommendations from this effort included employing all available species and habitat data of acceptable quality, and filling gaps with expert judgments. The formulation of case-specific quantitative targets, protecting both patterns and processes, and subject to change following evaluation, was also suggested. Success was found to depend largely on stakeholder involvement and a feeling of joint ownership.

as well as opportunities to maintain connectivity through landscape linkages. However, given the limited availability of species' distribution data, gap analyses have been conducted using indicators of biodiversity, such as particular species or groups of species (Terborgh and Winter, 1983; Pearson and Cassola, 1992; Bibby et al., 1992; Kremen et al., 1993; Launer and Murphy, 1994), physical attributes of the environment (Mackey et al., 1988; Kirkpatrick and Brown, 1994) or habitat types (Nilsson and Gotmark, 1992; Dinerstein and Wikramanayake, 1993; Keel et al., 1993), which are more likely to have been mapped. The assumption inherent in these analyses, that plant communities or other indicators accurately reflect physical factors (soil, moisture regime, aspect, elevation, temperature), may be violated. Vegetation cover, for example, is

**Box 11. Gap Analysis of the Global PA System**

Gap analysis was used to assess the effectiveness of the global PA network for species-level conservation (Rodrigues et al., 2004a), and to suggest areas for network expansion (Rodrigues et al., 2004b). The analyses focused on mammals, amphibians, turtles and freshwater tortoises, and threatened birds, the four terrestrial vertebrate groups for which global assessments were available. Many other species, such as aquatic, plant, and invertebrate taxa, were not assessed due to data limitations. Of the 11,633 species analyzed, at least 1,424 (12.2 percent) were not included in any protected area. Gap analysis was then used to begin identifying specific sites for future network expansion, focusing on irreplaceability and threats among these vertebrates (Rodrigues et al., 2004b). Unprotected areas of the world that have remarkably high conservation value and are under serious threat were identified, concentrated overwhelmingly in tropical and subtropical moist forests, particularly on tropical mountains and islands.

presumed to predict the distribution of target taxa accurately, and vertebrate distribution is assumed to be a good surrogate for diversity in other groups. In addition, specimen locality records or confirmed observations are used to refine or produce distribution maps, in combination with overlays of biotic or abiotic factors that may drive distributions. Gap analysis relies on distribution maps that may not be accurate because patterns are generally not well known, may not be representative, and may vary over time.

## Concluding Remarks

This module has described ways in which protected areas, the "single most important conservation tool" (Rodrigues et al., 2004b), can be designed to conserve biodiversity. Currently, there is a global system of protected areas that covers about 12% of the Earth's terrestrial surface through diverse international, regional, and national initiatives. This system may not be optimal, however many parks do achieve biodiversity conservation, sustainable development, and multiple use objectives. Sites can be chosen to protect specific taxa, enabling also the conservation of the ecosystems they occupy. International treaties or other initiatives serve to protect target habitats, such as wetlands, or ecological processes. Reserves can be designed to protect areas of high species diversity, to include representative species or habitats, or to protect against environmental variation such as climate change. PAs can be planned to optimize size, shape, complementarity, replication, and connectivity according to specific conservation goals. Zoning and stakeholder involvement can be effective tools for accommodating human objectives throughout the design process. Methods such as gap analysis and reserve selection algorithms provide a level of objectivity, consistency, and transparency to reserve planning.

However, many PAs are threatened or situated and planned in ways that fail to match conservation priorities (Chape et al., 2005), and questions remain regarding the implementation, management, and effectiveness of protected areas worldwide. To investigate ways in which the theoretical aspects of reserve planning play out in the real world, consider referring to the second NCEP module in this series *Protected Areas and Biodiversity Conservation II: Management and Effectiveness*.

## Acknowledgements

The following people are gratefully acknowledged: James P. Gibbs, Nora Bynum, Craig Starger and Camila Sibata.

## Terms of Use

This material is based on work supported by the National Science Foundation under the Course, Curriculum and Laboratory Improvement program (NSF 0127506), and the United States Fish and Wildlife Service (Grant Agreement No. 98210-1-G017).



## Literature Cited

Agardy T. 2000. Effects of fisheries on marine ecosystems: a conservationist's perspective. ICES Journal of Marine Science 57: 761-765.

Airamé, S., J.E. Dugan, K.D. Lafferty, H. Leslie, D.A. McArdle, and R.R. Warner. 2003. Applying ecological criteria to marine reserve design: a case study from the California Channel Islands. Ecological Applications 13: S170-S184.

Allin, C.W. 1990. International Handbook of National Parks and Nature Reserves. Greenwood Press, Greenwood, CT, USA.

Andelman, S., I. Ball, F. Davis, and D. Stoms. 1999. SITESV 1.0: An analytical toolbox for designing ecoregional conservation portfolios. The Nature Conservancy, Boise, Idaho.

Ando, A., J. Camm, S. Polasky, and A. Solow. 1998. Species distributions, land values, and efficient conservation. Science 279 (5359): 2126-2128.

Ayres, J., R. Bodmer, and R. Mittermeier. 1991. Financial considerations of reserve design in countries with high primate diversity. Conservation Biology 5: 109-114.

Ball, I.R. and H.P. Possingham. Undated. Marxan: a reserve system selection tool. Available from: www.ecology.uq.edu.au/marxan.htm.

Balmford, A. 2003. Conservation planning in the real world: South Africa shows the way. Trends In Ecology & Evolution 18 (9): 435-438.

Beck, M.W. and M. Odaya. 2001. Ecoregional planning in marine environments: identifying priority sites for conservation in the northern Gulf of Mexico. Aquatic Conservation: Marine and Freshwater Ecosystems 11:235-242.

Beier, P. and R. Noss. 1998. Do habitat corridors provide connectivity? Conservation Biology 11: 1255-1257.

Berkes F. 2004. Rethinking community-based conservation. Conservation Biology 18 (3): 621-630.

Bibby, C. J., N. J. Collar, M. J. Crosby, M. F. Heath, C. Imboden, T. H. Johnson, A. J. Long, A. J. Stattersfiel and S. J. Thirgood. 1992. Putting Biodiversity on the Map: Priority Areas for Global Conservation. Cambridge: International Council for Bird Preservation.

Bierregaard, R. O., Jr., C. Gascon, T. E. Lovejoy, and R. Mesquita, editors. 2001. Lessons from Amazonia: The Ecology and Conservation of a Fragmented Forest. Yale University Press, New Haven, CT.

Bishop, K., N. Dudley, A. Phillips and S. Stolton. 2004. Speaking a Common Language. The uses and performance of the IUNC System of Management Categories for Protected Areas. IUCN. Available from: http://www.iucn.org/themes/wcpa/pubs/pdfs/speakingacommonlanguage.pdf.

Brooks, T., A. Balmford, N. Burgess, J. Fjeldså, L. Hansen, J. Moore, C. Rahbek, and P. Williams. 2001. Toward a blueprint for conservation in Africa. BioScience 51: 613-624.

Brooks, T. M., M. I. Bakarr, T. Boucher, G.A.B. da Fonseca, C. Hilton-Taylor, J. M. Hoekstra, T. Moritz, S. Olivieri, J. Par-

rish, R. L. Pressey, A.S.L. Rodrigues, W. Sechrest, A. Stattersfield, W. Strahm, and S. N. Stuart. 2004. Coverage Provided by the Global Protected Area System: Is it Enough? BioScience 54 (12): 1081-91.

Brooks T.M., R. A. Mittermeier, G. A. B. da Fonseca, J. Gerlach, M. Hoffmann, J. F. Lamoreux, C. G. Mittermeier, J. D. Pilgrim, and A. S. L. Rodrigues. 2006. Global biodiversity conservation priorities. Science 313: 58-61.

Caro, T. and G. O'Doherty. 1999. On the use of surrogate species in conservation biology. Conservation Biology 13: 805-814.

Carr, M.H., and P.T. Raimondi. 1999. Marine protected areas as a precautionary approach to management. California Cooperative Oceanic Fisheries Investigations Reports 40: 71-76.

Ceballos, G., P.R. Ehrlich, J. Soberón, I. Salazar, and J.P. Fay. 2005. Global mammal conservation: What must we manage? Science 309 (5734): 603-607.

Chandrashekara, U. M. and S. Sankar. 1998. Ecology and management of sacred groves in Kerala, India. Forest Ecology and Management 112: 165-177.

Chape, S., L. Fish, P. Fox, and M. Spalding. 2003. United Nations List of Protected Areas. IUCN/UNEP, Gland Switzerland/ Cambridge UK. Available from: http://www.unep-wcmc.org/wdpa/unlist/2003_UN_LIST.pdf.

Chape, S., J. Harrison, M. Spalding, and I. Lysenko. 2005. Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. Philosophical Transactions of the Royal Society B 360: 443-455.

Collinge, S.K. 2000. Effects of grassland fragmentation on insect species loss, colonization, and movement patterns. Ecology 81 (8): 2211-2226.

Coppolillo, P., H. Gomez, M. Maisels, and R. Wallace. 2004. Selection criteria for suites of landscape species as a basis for site-based conservation. Biological Conservation 115 (3): 419-430.

Cork, S.J., T.W. Clark, and N. Mazur. 2000. Introduction: an Interdisciplinary Effort for Koala Conservation. Conservation Biology 14 (3): 606-609.

Cote, I.M., I. Mosqueira, and J.D. Reynolds. 2001. Effects of marine reserve characteristics on the protection of fish populations: a meta-analysis. Journal of Fish Biology 59: 178-189.

Dietz, J.M., A.J. Baker, and J.D. Ballou. 2000. Demographic evidence of inbreeding depression in wild golden lion tamarins. Pages 203-211 in A. Young and G. Clark, editors. Genetics, demography, and viability of fragmented populations. Cambridge University Press.

Dietz, T., E. Ostrom, and P.C. Stern. 2003. The struggle to govern the commons. Science 302 (5652): 1907-1912.

Dinerstein, E. and E. D. Wikramanayake. 1993. Beyond "hotspots": How to prioritize investments to conserve biodiversity in the Indo-Pacific region. Conservation Biology 7: 53–65.

Fernandes, L., J. Day, A. Lewis, S. Slegers, B. Kerrigan, D. Breen, D. Cameron, B. Jago, J. Hall, D. Lowe, J. Innes, J. Tanzer, V. Chadwick, L. Thompson, K. Gorman, M. Simmons, B. Barnett, K. Sampson, G. De'ath, B. Mapstone, H. Marsh, H. Possingham, I. Ball, T. Wardo, K. Dobbs, J. Aumend, D. Slater, and K. Stapleton. 2005. Establishing Representative No-Take Areas in the Great Barrier Reef: Large-Scale Implementation of Theory on Marine Protected Areas. Conservation Biology 19: 1733.

Gaston, K.J. 2000. Global patterns in biodiversity. Nature 405: 220-227.

Gell, F.R. and C.M. Roberts. 2003. Benefits beyond boundaries: the fishery effects of marine reserves. Trends In Ecology & Evolution 18 (9): 448-455.

Gonzalez, A., J.H. Lawton, F.S. Gilbert, T.M. Blackburn, and I. Evans-Freke. 1998. Abundance and distribution in a microecosystem. Science 281: 2045-2047.

Groves, C., L. Valutis, D. Vosick, B. Neely, K. Wheaton, J. Touval, and B. Runnels. 2000. Designing a geography of hope: A practitioner's handbook for ecoregional conservation planning. The Nature Conservancy, International Headquarters, Arlington VA. Available from http://www.conserveonline.org.

Haddad, N.M. and K.A. Baum. 1999. An experimental test of corridor effects on butterfly densities. Ecological Applications 9 (2): 623-633.

Haddad, N.M., D.R. Bowne, A. Cunninghan, B.J. Danielson,

D.J Levey, S. Sargent, and T. Spira. 2003. Corridor use by diverse taxa. Ecology 84 (3): 609-615.

Hale, M.L, P.W.W. Lurz, M.D.F. Shirley, S. Rushton, R.M. Fuller, and K. Wolff. 2001. Impact of landscape management on the genetic structure of red squirrel populations. Science 293: 2246-2248.

Halpern, B.S. and R.R. Warner. 2002. Marine reserves have rapid and lasting effects. Ecology Letters 5 (3): 361-366.

Hannah, L., G.F. Midgley and G. Hughes. 2005. The view from the Cape: Extinction risk, protected areas and climate change. Bioscience 55:231-242.

Hansen, A., and J. Rotella. 2002. Biophysical factors, land use, and species viability in and around nature reserves. Conservation Biology 16: 1112-1122.

Hobbs, R.J. 1992. The role of corridors in conservation: solution or bandwagon? TREE 7 (11): 389-392.

Howard, P., P. Viskanic, T. Davenport, F. Kigenyi, M. Baltzer, C. Dickinson, J. Lwanga, R. Matthews, and A. Balmford. 1998. Complementarity and the use of indicator groups for reserve selection in Uganda. Nature 394: 472-475.

Howard, P., T. Davenport, F. Kigenyi, P. Viskanic, M. Baltzer, C. Dickinson, J. Lwanga, R. Matthews, and E. Mupada. 2000. Protected area planning in the tropics: Uganda's national system of forest nature reserves. Conservation Biology 14: 858-875.

Howard, T.G., J.W. Jaycox, and T.W. Weldy. 2002. Rare Species and Significant Natural Communities of the Significant Biodiversity Areas in the Hudson River Valley. New York Natural Heritage Program. Available from: www.nynhp.org

Hulme, D. and M.W. Murphree, editors. 2001. African wildlife and livelihoods: the promise and performance of community conservation. James Currey, Oxford, UK.

IUCN [The World Conservation Union]. 1994. Guidelines for Protected Area Management Categories. IUCN, Gland, Switzerland and Cambridge, UK.

IUCN. 2003. Protected Areas Media Brief. Available from: http://www.iucn.org/news/pambrief.pdf.

IUCN. 2000. Financing Protected Areas - Guidelines for Protected Area Managers. Available from: http://www.iucn.org/themes/wcpa/pubs/guidelines.htm.

Kareiva, P. and M. Marvier. 2003. Conserving biodiversity coldspots. American Scientist 91: 344-351.

Keel, S., A. H. Gentry, and L. Spinzi. 1993. Using vegetation analysis to facilitate the selection of conservation sites in eastern Paraguay. Conservation Biology 7: 66–75.

Kerr, J.T. 1997. Species richness, endemism, and the choice of areas for conservation. Conservation Biology 11 (5): 1094-1100.

Kirkpatrick, J.B. and M.J. Brown. 1994. A comparison of direct and environmental domain approaches to planning reservation of forest higher-plant communities and species in Tasmania. Conservation Biology 8, 217–224.

Kremen, C., R. K. Colwell, T. L. Erwin, D. D. Murphy, R. F. Noss, and M. A. Sanjayan. 1993. Terrestrial arthropod assemblages: their use in conservation planning. Conservation Biology 7: 796–808.

Lambeck, R. 1997. Focal species: a multi-species umbrella for nature conservation. Conservation Biology 11: 849-856.

Lambert, J.D. and M.H. Carr. 1998. The Paseo Pantera Project: A case study using GIS to improve continental-scale conservation planning. Pages 138-147 in B.G Savitsky and T.E. Lacher, Jr., editors. GIS Methodologies for Developing Conservation Strategies: Tropical Forest Recovery and Wildlife Management in Costa Rica. Columbia University Press, New York.

Landres, P. B., J. Verner, and J.W. Thomas. 1988. Ecological uses of vertebrate indicator species: a critique. Conservation Biology 2: 316-327.

Launer, A. E. and D. D. Murphy. 1994. Umbrella species and the conservation of habitat fragments: a case of a threatened butterfly and a vanishing grassland ecosystem. Biological Conservation 69:145-153.

Lemieux, C.J. and D.J. Scott. 2005. Climate change, biodiversity conservation and protected areas planning in Canada. The Canadian Geographer, 49 (4): 384-399.

MacArthur, R.H. and E.O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, N.J.

Mackey, B. G., H. A. Nix, M. F. Hutchinson, J. P. MacMahon, and P. A. Fleming. 1988. Assessing representativeness

of places for conservation reservation and heritage listing. Environmental Management 12:501 514.

Margules, C., and R. Pressey. 2000. Systematic conservation planning. Nature 405: 243-253.

Matlack, G.R. and J.A. Litvaitis. 1999. Chapter 6. Forest edges. Pages 210-233 in M. Hunter, editor. Maintaining Biodiversity in Forest Ecosystems. Cambridge University Press, Cambridge, U.K.

McClanahan, T. R. and B. Kaunda-Arara. 1996. Fishery recovery in a coral-reef marine park and its effect on the adjacent fishery. Conservation Biology 10(4): 1187-1199.

McShane, T. 2003. The devil in the detail of biodiversity conservation. Conservation Biology 17: 1-3.

Miller, K., E Chang and N. Johnson. 2001. Defining Common Ground for the Mesoamerican Biological Corridor. World Resources Institute. Available from: http://pdf.wri.org/esmoamerica_english.pdf.

Myers, N., R. Mittermeier, C. Mittermeier, G. Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853-858.

NAS [National Academy of Sciences]. 2001. Marine protected areas: Tools for sustaining ocean ecosystems. Marine Academy Press, Washington, D.C.

Newmark, W. D. 1995. Extinction of mammal populations in western North American National Parks. Conservation Biology 9: 512-526.

Newmark, W.D. 1996. Insularization of Tanzanian parks and the local extinction of large mammals. Conservation Biology 10: 1549-1556.

Nilsson, C. and F. Gotmark. 1992. Protected areas in Sweden: is natural variety adequately represented? Cons. Biology 6(2): 232-242.

Noss, R.F. 1987. From plant communities to landscapes in conservation inventories - A look at The Nature Conservancy (USA). Biological Conservation 41 (1): 11-37.

Noss, R. 2003. A Checklist for wildlands network designs. Conservation Biology 17: 1270-1275.

Oates, J.F. 1999. Myth and reality in the rain forest: how conservation strategies are failing in West Africa. University of California Press, Berkely, CA.

O'Connor, C., M. Marvier, and P. Kareiva. 2003. Biological vs. social, economic and political priority-setting in conservation. Ecology Letters 6: 706-711.

Olson, D.M. and E. Dinerstein. 2002. The Global 200: priority ecoregions for global conservation. Annals of the Missouri Botanical Garden 89: 199-224.

Olson, D., E. Dinerstein, E. Wikramanayake, N. Burgess, G. Powell, E. Underwood, JA D'Amico, I. Itoua, H. Strand, J. Morrison, C. Loucks, T. Allnutt, T. Ricketts, Y. Kura, J. Lamoreux, W. Wettengel, and P. H. Kassem. 2001. Terrestrial ecoregions of the world: a new map of life on earth. BioScience 51: 933-938.

Orme, C. D. L., Richard G. Davies, Malcolm Burgess, Felix Eigenbrod, Nicola Pickup, Valerie A. Olson, Andrea J. Webster, Tzung-Su Ding, Pamela C. Rasmussen, Robert S. Ridgely, Ali J. Stattersfield, Peter M. Bennett, Tim M. Blackburn, Kevin J. Gaston and Ian P. F. Owens. 2005. Global hotspots of species richness are not congruent with endemism or threat. Nature 436: 1016-1019.

Parmesan, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37-42.

Pauly, D., V. Christensen, S. Guénette, T.J. Pitcher, U.R. Sumaila, C.J. Walters, R. Watson and D. Zeller. 2002. Towards sustainability in world fisheries. Nature 418: 689-695.

Pearson, D. L. and F. Cassola. 1992. World-wide species richnes patterns of tiger beetles (Coleoptera: Cicindelidae): Indicator taxon for biodiversity and conservation studies. Conservation Biology 6: 376-391.

Pearson, R.G. and T.P. Dawson. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography, 12, 361-371.

Peters, R. L., and J. D. Darling. 1985. The greenhouse effect and nature reserves. BioScience 35: 707–717.

Pimm, S. and J. Lawton. 1998. Planning for biodiversity. Science 279: 2068-2069.

Ponce, C.F. and F. Ghersi. 2005. Cordillera del Condor (Peru-Ecuador). World Parks Congress. Available from: http://www.earthlore.ca/clients/WPC/English/grfx/sessions/PDFs/session_2/Ponce.pdf.

Powell, G.V.N., Barborak, J., and Rodriguez, M. 2000. Assess-

ing representativeness of protected natural areas in Costa Rica for conserving biodiversity: a preliminary gap analysis. Biological Conservation 93: 35-41.

Prendergast, J., R. Quinn, and J. Lawton. 1999. The gaps between theory and practice in selecting nature reserves. Conservation Biology 13:484-492.

Prendergast J.R., R. M. Quinn, J.H. Lawton, B.C. Eversham, and D.W. Gibbons. 1993. Rare species, The coincidence of diversity hotspots and conservation strategies. Nature 365 (6444): 335-337.

Pressey, R. 1994. Ad hoc reservations: forward or backward steps in developing representative reserve systems? Conservation Biology 8: 662-668.

Pressey, R. 1999. Applications of irreplaceability analysis to planning and management problems. Parks (IUCN) 9: 42-51.

Pressey, R. 2000. Towards a framework for implementing a representative reserve system of forest protected areas. Pages 13-30 in The Design and Management of Forest Protected Areas Papers presented at the Beyond the Trees Conference 8-11 May 2000, Bangkok Thailand Available from: www.panda.org/downloads/forests/beyondthetrees.pdf.

Pressey, R., and R. Cowling. 2001. Reserve selection algorithms in the real world. Conservation Biology 15:275-277.

Pressey, R. L., P. H. Possingham and R. J. Day. 1997. Effectiveness of Alternative Heuristic Algorithms for Identifying Indicative Minimum Requirements for Conservation Reserves. Biological Conservation 80: 207-219.

Pressey, R.L., R.M. Cowling, and M. Rouget. 2003. Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa. Biological Conservation 112: 99-127.

Redford, K.H., Sanderson, E.W., Robinson, J.G., Vedder, A., 2000. Landscape Species and Their Conservation: Report From a WCS Meeting, May 2000. Wildlife Conservation Society, Bronx, NY.

Revilla, E., F. Palomares, and M. Delibes. 2001. Edge-Core Effects and the Effectiveness of Traditional Reserves in Conservation: Eurasian Badgers in Doñana National Park. Conservation Biology 15 (1): 148-158.

Roberts, C.M. 2002. Response. Science 295 (5558): 1233b.

Roberts, C.M., C.J. McClean, J.E.N. Veron, J.P. Hawkins, G.R. Allen, D.E. McAllister, C.G. Mittermeier, F.W. Schueler, M. Spalding, F. Wells, C. Vynne, and T.B. Werner. 2002. Marine biodiversity hotspots and conservation priorities for tropical reefs. Science 295: 1280-1284.

Rodrigues, A.S.L., S.J. Andelman, M.I. Bakarr, L. Boitani, T.M. Brooks, R.M. Cowling, L.D.C. Fishpool, G.A.B. da Fonseca, K.J. Gaston, M. Hoffmann, J.S. Long, P.A. Marquet, J.D. Pilgrim, R.L. Pressey, J. Schipper, W. Sechrest, S.N. Stuart, L.G. Underhill, R.W. Waller, M.E.J. Watts, and X. Yan. 2004a. Effectiveness of the global protected area network in representing species diversity. Nature 428 (6983): 640-643.

Rodrigues, A.S.L., H. Resit Akçakaya, Sandy J. Andelman, Mohamed I. Bakarr, Luigi Boitani, Thomas M. Brooks, Janice S. Chanson, Lincoln D. C. Fishpool, Gustavo A. B. Da Fonseca, Kevin J. Gaston, Michael Hoffmann, Pablo A. Marquet, John D. Pilgrim, Robert L. Pressey, Jan Schipper, Wes Sechrest, Simon N. Stuart, Les G. Underhill, Robert W. Waller, Matthew E. J. Watts, Xie Yan. 2004b. Global Gap Analysis: Priority regions for expanding the global protected-area network. BioScience 54(12): 1092-1100

Root, T. L., J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweig, and J. A. Pounds. 2003. Fingerprints of global warming on animals and plants. Nature 421:57–60.

Rosenberg, D.K., B.R. Noon, and E.C. Meslow. 1997. Biological corridors: form, function, and efficacy. BioScience 47(10): 678-687.

Ruiz-Perez, M., M. Almeida, S. Dewi, E.M. Costa, M.C. Pantoja, A. Puntodewo, A.A. de Postigo, and A.G. de Andrade. 2005. Conservation and development in Amazonian extractive reserves: the case of Alto Jurua. Ambio. 34(3): 218-23.

Runte, A. 1997. National parks: the American experience. University of Nebraska Press, Lincoln, Nebraska, USA.

Salafsky, N., R. Margoluis, K. Redford, and J. Robinson. 2002. Improving the practice of conservation: a conceptual framework and research agenda for conservation science. Conservation Biology. 16: 1469-1479.

Sanderson, E. W., K. H. Redford, A. Vedder, P. B. Coppolillo, and S. E. Ward. 2002. A conceptual model for conservation planning based on landscape species requirements. Landscape and Urban Planning 58: 41-56.

Schultz, C.B. 1998. Dispersal behavior and its implications for reserve design in a rare Oregon butterfly. Conservation Biology 12 (2): 284-292.

Scott, J., and B. Csuti. 1997. Noah worked two jobs. Conservation Biology 11: 1255-1257.

Scott, M.J., F. Davis, B. Cusuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T.C. Edwards, J. Ulliman, and R.G. Wright. 1993. GAP Analysis: A Geographic Approach to Protection of Biological Diversity. Wildlife Monographs 123:1-41.

Scott J.M., F.W. Davis, R. G. McGhie, R. G. Wright, C. Groves, and J. Estes. 2001. Nature Reserves: Do They Capture The Full Range Of America's Biological Diversity? Ecological Applications 11 (4): 999–1007.

Sechrest, W., T.M. Brooks, G.A.B. da Fonseca, W.R. Konstant, R.A. Mittermeier, A. Purvis, A.B. Rylands, and J.L. Gittleman. 2002. Hotspots and the conservation of evolutionary history. Proceedings of the National Academy of Sciences 99(4): 2067-2071.

Shaver, D. 1989. Padre Island National Seashore Kemp's Ridley sea turtle project 1989 report. U.S. Department of the Interior, National Park Service.

Silva, M. 2005. The Brazilian Protected Areas Program. 2005. Conservation Biology 19 (3): 608-611.

Soulé, M.E. and D. S. Simberloff. 1986. What do genetics and ecology tell us about the design of nature reserves? Biological Conservation, 35(1): 19-40.

Soulé, M.E. and M.A. Sanjayan. 1998. Conservation targets: do they help? Science 279: 2060-2061

Soulé, M. E. and J. Terborgh. 1999. Conserving nature at regional and continental scales? A scientific program for North America. BioScience 49 (10): 809-817.

Sterling, E.J. 2002. Conservation: Definition and History. Pages 246-249 in Niles Eldridge, editor. Life on Earth: An Encyclopedia of Biodiversity, Ecology, and Evolution.

Tellez-Valdes O. and P. Davila-Aranda. 2003. Protected areas and climate change: A case study of the cacti in the Tehuacán-Cuicatlán biosphere reserve, México. Conservation Biology 17(3): 846-853.

Terborgh J. and B. Winter. 1983. A method for siting parks and reserves with special reference to Colombia and Ecuador. Biological Conservation 27 (1): 45-58.

Terborgh, J., C. Van Schai, L.C. Davenport, and M. Rao, editors. 2002. Making parks work: strategies for preserving tropical nature. Island Press, Washington DC.

Tewksbury, J.J., D.J. Levey, N.M. Haddad, S. Sargent, J.L. Orrock, A. Weldon, B.J. Danielson, J. Brinkerhoff, E.I. Damschen, and P. Townsend. 2002. Corridors affect plants, animals, and their interactions in fragmented landscapes. Proceedings Of The National Academy Of Sciences Of The United States Of America 99 (20): 12923-12926.

Thomas, C.D., A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus, M. F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A. S. van Jaarsveld, G. F. Midgley, L. Miles, M. A. Ortega-Huerta, A. T. Peterson, O. L. Phillips, and S. E. Williams. 2004. Extinction risk from climate change. Nature 427: 145-148.

Trexler, J.C and J. Travis. 2000. Can marine protected areas restore and conserve stock attributes of reef fishes? 66(3): 853-873.

UNEP-WCMC. 2003. World Database on Protected Areas (WDPA) Version 6.0. Available from: http://sea.unep-wcmc.org/wdbpa.

Van Jaarsveld, A., S. Freitag, S. Chown, C. Muller, S. Koch, H. Hull, C. Bellamy, M. Krüger, S. Endrödy-Younga, M. Mansell, and C. Scholtz. 1998. Biodiversity assessment and conservation strategies. Science 279: 2106-2108.

Vane-Wright, R.I., C.J. Humphries, and P.H. Williams. 1991. What to protect?-systematics and the agony of choice. Biological Conservation 55: 235-254.

Villa, F., L. Tunesi, and T. Agardy. 2002. Zoning Marine Protected Areas through Spatial Multiple-Criteria Analysis: the Case of the Asinara Island National Marine Reserve of Italy. Conservation Biology 16 (2): 515-526.

Ward, T.J., M.A. Vanderklift, A.O. Nicholls, and R.A. Kenchington. 1999. Selecting marine reserves using habitats and species assemblages as surrogates for biological diversity.

Ecological Applications 9 (2): 691-698.

Western, D. and M. Wright, editors. 1994. Natural connections: perspectives in community-based conservation. Island Press, Washington DC.

White, A.T., C.A. Courtney, and A. Salamanca. 2002. Experience with Marine Protected Area Planning and Management in the Philippines. Coastal Management 30: 1-26.

Wilcove, D.S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48 (8): 607-615

Woodroffe, R. and J.R. Ginsberg. 1998. Edge effects and the extinction of populations inside protected areas. Science 280 (5372): 2126-2128

World Resources Institute. 2003. Biodiversity and Protected Areas Country Profiles. Available from: http://earthtrends.wri.org/index.cfm.

Yellowstone to Yukon Conservation Initiative. 1998. A Sense of Place. Available from: www.y2y.net/science/conservation/y2yatlas.pdf.

## Glossary

Biogeographic: A geographic range delineated using the presence of various species, both living and fossilized.

Biological diversity: The variety of life on Earth at all its levels, from genes to ecosystems, and the ecological and evolutionary processes that sustain it.

Biomes: Represent global-scale ecological variation in the structure, dynamics, and complexity of biological communities and ecosystems.

Community: A group of plants or animals that occupy a shared environment and interact.

Corridor: A strip of vegetation or other habitat that connects fragmented areas, which may have been historically connected. The intention is to enable movement between the two fragments.

Dispersal: The spreading of organisms across a physical scale, such as seeds or individuals, or movement away from the birth site.

Ecological process: The interactions between organisms, between communities, and between organisms and abiotic resources.

Ecosystem: An assemblage of organisms and the physical environment in which it exchanges energy and matter.

Edge: The area of transition between two different habitats.

Endemism: When an organism is native to, or found, only in one area.

Flagship species: Animals or plants that generate a large amount of popular interest; often used in conservation to protect less charismatic species that share habitat with the flagship species.

Gap analysis: An effort to use mapping (mainly using Geographic Information Systems - GIS) to uncover areas that are not being protected through existing conservation efforts.

Indicator species: A species whose well-being is taken to be reflective of the condition of some more general ecological or environmental condition/process.

IUCN: The International Union for the Conservation of Nature and Natural Resources, also known as the World Conservation Union (www.iucn.org).

Keystone species: A species that has an exceptionally important role in preserving the functionality and diversity of their community.

Landscapes: Areas that contain heterogeneous collections of ecosystems.

Network: A group of protected areas that are linked.

Phylogenetic distinctiveness: A measure of the evolutionary uniqueness of a taxon relative to others.

Realms: Continent-scale regions distinguished by characteristic biota that reflect shared evolutionary histories.

Replication: The inclusion of several areas of similar habitat within a reserve or network.

Reserve selection algorithm: Rule-based (heuristic), statistical, or mathematical algorithms used to build reserves, systems and networks according to user specifications.

Sink: A population that is not self-sustaining and relies on immigration to survive.

Source: A population from which individuals emigrate to other areas.

Species diversity: A measure of the species richness, but weighted to express abundance either based on the number of individuals or biomass of each species.

Species richness: The number of different species in an area.

Stakeholder: A person or group of people with an interest in any impact that an action might have.

Umbrella species: A species whose protection will also provide protection for other species, usually through habitat preservation.

Zones: Areas within a protected area that have different levels of protection.